In re Patent Application of:
**Boulanger ET AL.**
Serial No. **09/856,710**
Filed: **February 26, 2002**

## IN THE CLAIMS

1. (currently amended) A tunable frequency-converting device for generating~~, through interaction(s) with three or four waves from one or more incident optical radiations, one or more~~ an emerging optical beam having a first frequency from an incident optical beam having a second frequency ~~radiations, at least tunable in frequency,~~ ~~characterized in that it is essentially formed by~~ comprising:

a crystal with a non-linear optical property having a curved input surface for receiving the incident optical beam ensuring substantially normal incidence of the incident optical beam, and a curved output surface for transmitting the emerging optical beam, the crystal or the incident optical beam being rotatable around an ~~of which defines a cylindrical volume of revolution, in a complete or a truncated way, on at least two opposite and symmetrical quadrants with respect to its~~ axis of revolution, which is perpendicular to a normal to the input surface, for tuning the frequency of the emerging optical beam; and ~~, or else even in a partial way on only one of such quadrants, and~~ ~~in that it further comprises~~

an optical system for confining and focussing said incident optical beam through the crystal via the input surface and ~~radiation(s) on~~ a ~~the~~ central portion~~(s)~~ of said crystal ~~on the one hand~~, and for collimating and directing said emerging optical beam from the output surface ~~radiation(s) on the other hand~~.

2. (currently amended) The device according to claim 1, wherein ~~characterized in that~~ said crystal has a volume

selected from a cylinder volume ~~(1)~~, a cylindroid volume ~~(2)~~, a truncated cylinder volume ~~(3)~~, a truncated cylindroid volume ~~(4)~~, a partial cylinder volume, and a partial ~~or~~ cylindroid volume ~~(5)~~.

3. (currently amended) The device according to claim 2, wherein ~~any of the preceding claims, characterized in that~~ said ~~cylindrical~~ volume has a section selected from a circular section and an elliptical section.

4. (currently amended) The device according to claim 1, wherein ~~any of the preceding claims, characterized in that~~ said crystal includes at least one hyperpolarizable chemical entity.

5. (currently amended) The device according to claim 1, wherein ~~any of the preceding claims, characterized in that~~ said crystal is a crystal selected from a crystal of $LiTaO_3$, $KTiOPO_4$, $KTiOAsO_4$, $RbTiOPO_4$, $RbTiOAsO_4$, $CsTiOAsO_4$, $\beta.Ba_2BO_4$, $LiB_3O_5$ ~~$LiB_2O_5$~~, $KNbO_3$, $LiIO_3$, $LiNbO_3$, $KD_2PO_4$, $KH_2PO_4$, $NH_4H_2PO_4$, $CsD_2AsO_4$ ~~$CsD_2ASO_4$~~, $CsH_2AsO_4$, $AgGaS_2$, $AgGaSe_2$ ~~$AgGAsE_2$~~, $ZnGeP_2$, $Tl_3AsSe_3$ and a crystal of GaAs.

6. (currently amended) The device according to claim 1, wherein ~~any of the preceding claims, characterized in that the size of~~ said crystal is selected from a micrometric size, a millimetric size and a centimetric size.

7. (currently amended) The device according to claim 1, wherein ~~any of the preceding claims, characterized in that~~ said optical system ~~is essentially formed by~~ comprises two components, placed on opposite ~~both~~ sides of said crystal, and

selected from a convergent lens ~~length~~, a divergent lens ~~length~~, a set of lenses, a reflecting surface or mirror with a concave surface facing ~~the concavity orientated on the side of~~ said crystal, and a reflecting surface or mirror with a convex surface facing ~~the concavity orientated on the opposite side of~~ said crystal.

8. (currently amended) The device according to claim 1, further comprising a rotary device, which rotates about a rotary mechanical axis, for supporting the crystal, wherein ~~any of the preceding claims, characterized in that~~ the axis of revolution of said crystal coincides with the ~~a~~ rotary mechanical axis ~~so that the crystal may rotate around its axis~~.

9. (currently amended) The device according to claim 1, wherein ~~any of claims 1 to 8, characterized in that~~ said crystal is a crystal with a phase matching ~~tuning~~ property through birefringence ~~double refraction~~.

10. (currently amended) The device according to claim 9, wherein ~~characterized in that~~ said crystal is a monocrystalline crystal.

11. (currently amended) The device according to claim 1, wherein ~~any of claims 1 to 8, characterized in that~~ said crystal is a crystal with a quasi phase matching ~~tuning~~ property.

12. (currently amended) The device according to claim 11, wherein ~~characterized in that~~ said crystal has~~, along the direction of propagation of the sought after radiations,~~ a

periodically alternating juxtaposition of monocrystalline domains along a direction of propagation of the emerging optical beam.

13. Cancelled

14. (currently amended) The device according to claim 1, wherein ~~any of the preceding claims, characterized in that~~ said crystal is ~~contains direction(s) provide a maximum efficiency of the interaction, so that they are~~ accessible to said incident optical beam ~~radiation(s)~~ under substantially normal incidence ~~or close to the normal~~ on ~~one or more~~ the input surface~~(s)~~ of said crystal ~~defining a cylindrical volume of revolution,~~ either by rotation of said crystal around the ~~its~~ axis of revolution, or by rotation of said incident optical beam ~~radiations~~ around said crystal in a plane orthogonal to the axis of revolution of said crystal.

15. (currently amended) The device according to claim 1, wherein ~~any of the preceding claims, characterized in that~~ said incident optical beam comprises a plurality of ~~radiation(s) comprise (each) one, two, three or four equal or different~~ frequencies, with colinear or non-colinear wave vectors~~, and under normal incidence or close to the normal on one or more surfaces of said crystal defining a cylindrical volume of revolution~~.

16. (currently amended) The device according to claim 1, wherein ~~any of the preceding claims, characterized in that~~ said crystal has a network of monocrystalline domains selected from a network of plane monocrystalline domains, a network of

circular monocrystalline domains, and a network of elliptical monocrystalline domains.

17. (currently amended) The device according to claim 1, wherein ~~any of the preceding claims, characterized in that~~ said crystal has a network of periodically alternating domains, optionally surrounded by a non-alternating monocrystalline crown ~~(c)~~.

18. (currently amended) The device according to claim 1, wherein ~~any of the preceding claims, characterized in that~~ said incident optical beam is a ~~radiations are~~ laser beam ~~radiation(s)~~, ~~notably~~ comprising one or more laser beams ~~radiations~~ selected from a fixed frequency laser beam ~~radiation~~ and a tunable frequency laser beam ~~radiation~~.

19. (currently amended) The device according to claim 1, wherein ~~any of the preceding claims, characterized in that said interaction(s)~~ an interaction between electro-magnetic waves from the incident and emerging optical beams is ~~are interactions (s) selected from~~ a three-wave interaction or a four-wave interaction.

20. (currently amended) The device according to claim 19, wherein ~~any of the preceding claims, characterized in that~~ said crystal has a non-centrosymmetric structure so that said crystal ~~device~~ provides a three-wave interaction.

21. (currently amended) The device according to claim 19, further comprising at least one additional incident optical beam, and at least one additional emerging optical beam; wherein ~~any of the preceding claims, characterized in that~~

~~said~~ ~~or at least one of~~ said incident optical beams comprise ~~radiation(s) comprises~~ two frequencies for a three-wave interaction, or three frequencies for a four-wave interaction, and wherein ~~in that said or~~ at least one of said emerging optical beams ~~radiation(s)~~ comprise a frequency which corresponds to the sum of said two, or~~, if required,~~ said three frequencies comprised in said incident optical ~~radiation(s)~~ beams.

22. (currently amended) The device according to claim 1, wherein ~~any of the preceding claims, characterized in that said or at least one of~~ said first frequency ~~emerging optical radiation(s) comprise a frequency which~~ is equal to the double or the triple of the second ~~a~~ frequency ~~comprised in said or at least one of said incident optical radiation(s)~~.

23. (currently amended) The device according to claim 19, further comprising at least one additional incident optical beam, and at least one additional emerging optical beam; wherein ~~any of the preceding claims, characterized in that said or at least one of~~ said incident optical beams ~~radiation(s)~~ comprise two frequencies for a three-wave interaction, or three frequencies for a four-wave interaction; and wherein ~~in that said or~~ at least one of said emerging optical beams ~~radiation(s)~~ comprise a frequency, which corresponds to a difference between said two, or ~~if required,~~ said three frequencies comprised in said incident optical beams ~~radiation(s)~~.

24. (currently amended) The device according to claim 19, wherein ~~any of the preceding claims, characterized in that said or at least one of~~ said emerging optical beam

~~radiation(s)~~ comprises two frequencies for a three-wave interaction, or three frequencies for a four-wave interaction, the sum of which is equal to a frequency comprised in ~~said or at least one of~~ said incident optical beam ~~radiation(s)~~.

25. (currently amended) The device according to claim 19, wherein ~~any of the claims 1 to 24, characterized in that said or at least one of~~ said interaction~~(s)~~ is an interaction with colinear wave vectors.

26. (currently amended) The device according to claim 19, wherein ~~any of claims 1 to 24, characterized in that~~ said interaction is an interaction with non-colinear wave vectors.

27. (currently amended) The device according to claim 19, wherein ~~any of the preceding claims, characterized in that said or at least one of~~ said interaction~~(s)~~ is an interaction selected from an optical parametric amplification, and a generation of second or third harmonic.

28. (currently amended) The device according to claim 19, wherein ~~any of the preceding claims, characterized in that~~ said crystal is placed inside a cavity providing a resonant interaction, and wherein ~~in that~~ said optical system ~~for confining and focussing said incident optical radiation(s) on the central portion(s) of said crystal on the one hand, and for collimating and directing said emerging optical radiation(s) on the other hand,~~ is placed outside said cavity.

29. (currently amended) The device according to claim 28, wherein ~~characterized in that~~ said resonant interaction is an interaction with three or four waves selected from an optical

parametric oscillation, an optical parametric amplification, and a generation of second or third harmonics.

30. (currently amended) The device according to claim 28, wherein ~~or 29, characterized in that~~ said cavity includes input and output reflecting surfaces facing each other providing resonance for at least one of the interacting waves.

31. (currently amended) The device according to ~~any~~ claim 30, wherein ~~characterized in that~~ said input reflecting surface is selected from a plane reflecting surface and a reflecting surface having a radius of curvature, with a concave surface facing ~~the concavity selected from a concavity orientated on the side of~~ said crystal or a convex surface facing said crystal, ~~and a concavity orientated on the opposite side,~~ in order to optimize the oscillation threshold and the stability of the cavity.

32. (currently amended) The device according to claim 30, wherein ~~or 31, characterized in that~~ said at least one resonant wave has a non-zero double refraction angle ρ, and wherein ~~in that~~ said output reflecting surface has a concave surface facing ~~a radius of curvature, with a concavity selected from a concavity orientated on the side of~~ said crystal or a convex surface facing ~~and a concavity orientated on the opposite side of~~ said crystal, so that the outgoing and returning beams coincide.

33. (currently amended) The device according to claim 30, wherein ~~any of the claims 30-32, characterized in that~~ said at least one resonant wave has a non-zero double refraction angle ρ, and wherein ~~in that~~ said output reflecting surface is

placed at a distance ~~(d)~~ from said crystal and has a radius of curvature R, the respective values of which satisfy equation $R = d - L$ with d larger than L for a concavity orientated on the side of said crystal, or the equation $R = L - d$ with d less than L for a concavity orientated on the opposite side of said crystal, with L defined as $L = R_c\ (\cos(2\rho) + (\sin(2\rho) / \tan(\rho_e)) - 1)$, with $R_c$ the radius of the cylindrical volume of revolution, $\rho$ the double refraction angle and with $\rho_e$ defined by $\rho_e = \arcsin(n \sin(2\rho) - 2\rho)$, with n being the refractive index of said at least one wave for which resonance is sought.

34. (currently amended) The device according to claim 30, wherein ~~or 31, characterized in that~~ said at least one resonant wave has a zero double refraction angle $\rho$, and wherein ~~in that~~ said output reflecting surface is selected from a plane reflecting surface and a reflecting surface having a radius of curvature, with a concave surface facing ~~the concavity selected from a concavity orientated on the side of~~ said crystal or a convex surface facing said crystal ~~and a concavity orientated on the opposite side,~~ in order to optimize the oscillation threshold and the stability of the cavity.

35. (currently amended) The device according to claim 1, ~~any of the preceding claims, characterized in that it~~ further comprising ~~comprises~~ means for thermostatic control of said crystal.

36. (currently amended) The device according to claim 1, wherein ~~any of the preceding claims, characterized in that~~

said crystal is held at a temperature different from room temperature.

37. (currently amended) The device according to claim 1, ~~any of the preceding claims, characterized in that it~~ further comprising ~~comprises~~ means for applying a static or low frequency electric field to the inside of said crystal.

38. (currently amended) The device according to claim 1, ~~any of the preceding claims, characterized in it~~ further comprising ~~comprises~~ a pair of electrodes placed on ~~the~~ opposite faces of said crystal.

39. (currently amended) The device according to claim 1, wherein the device ~~any of the preceding claims, characterized in that it~~ forms a component selected from a spectroscope component, a remote detection system component, a remote transmission system component, a remote guiding system component, a LIDAR system component, an optronic counter-measure system component.

40. (currently amended) A method for generating an optical beam ~~radiation at least~~ tunable in frequency, by implementing ~~characterized in that it implements~~ a device according claim 1 ~~to any of the preceding claims~~.

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**IN THE FIGURES**

Replace Figure 2 with the enclosed Figures 2a to 2g.

## IN THE DESCRIPTION

**Page 1, line 1**

Change the title to read: "A Tunable Frequency-Converting Optical Device".

**Page 21, lines 18 to 25**

- Figs 2a to 2g illustrate ~~Fig. 2 illustrates~~ different embodiments 1,2,3,4,5 of a crystal belonging to the device according to the invention, the hatched surfaces represent the surfaces of said crystals on which electrodes (electro-optical effect) may advantageously be placed, each reference number 1,2,3,4,5 designates a volume which may have a circular or elliptical section, each crystal is placed between two lenses $L_1$ and $L_2$,

**Page 29, line 17 to Page 30, line 12**

Example 2: Forms of the non-linear crystal

Figs 2a to 2g illustrate ~~Fig. 2 illustrates~~ various embodiments of a crystal belonging to the device according to the invention, the hatched surfaces represent surfaces of said crystal on which electrodes may be advantageously placed (for the electro-optical effect). Reference numbers 1 and 2, each refer to a crystal with a non-linear optical property having a completely cylindrical volume of revolution (reference 1: cylinder; reference 2: cylindroid), reference 3 and 4 refer to a crystal with a non-linear optical property having a cylindrical volume of revolution in a truncated way on opposite and symmetrical quadrants with respect to its axis of revolution, (reference 3: truncated cylinder; reference 4: truncated cylindroid), reference 5 refers to a crystal with a

non-linear optical property corresponding to a portion of said volumes 1 or 2 along planes containing the axis of revolution (reference 5: partial cylinder or cylindroid). Said volumes of cylinder 1 and cylindroid 2 may have a circular section or an elliptical section; such a section may notably be considered along an orthogonal plane to the axis of revolution. Electrodes may be advantageously placed on both sides of a crystal according to different configurations, which ~~they~~ are illustrated in Figs. 2a to 2g ~~Fig. 2~~ by a pair of hatched surfaces. For the crystals of volume 3 or 4, two of these configurations are illustrated: a pair of horizontally orientated electrodes or a pair of vertically orientated electrodes.

**Page 25, lines 5 to 11**

$$\omega_1 n^+(\omega_1,\theta,\Phi) + \omega_2 n^-(\omega_2,\theta,\Phi) + \omega_3 n^-(\omega_3,\theta,\Phi) = \omega_4 n^-(\omega_4,\theta,\Phi) \quad \underline{\textbf{(2a)}}$$

$$\omega_1 n^-(\omega_1,\theta,\Phi) + \omega_2 n^-(\omega_2,\theta,\Phi) + \omega_3 n^+(\omega_3,\theta,\Phi) = \omega_4 n^-(\omega_4,\theta,\Phi) \quad \underline{\textbf{(2b)}}$$

$$\omega_1 n^-(\omega_1,\theta,\Phi) + \omega_2 n^+(\omega_2,\theta,\Phi) + \omega_3 n^-(\omega_3,\theta,\Phi) = \omega_4 n^-(\omega_4,\theta,\Phi) \quad \underline{\textbf{(2c)}}$$

$$\omega_1 n^-(\omega_1,\theta,\Phi) + \omega_2 n^-(\omega_2,\theta,\Phi) + \omega_3 n^+(\omega_3,\theta,\Phi) = \omega_4 n^-(\omega_4,\theta,\Phi) \quad \underline{\textbf{(2d)}}$$

$$\omega_1 n^+(\omega_1,\theta,\Phi) + \omega_2 n^+(\omega_2,\theta,\Phi) + \omega_3 n^-(\omega_3,\theta,\Phi) = \omega_4 n^-(\omega_4,\theta,\Phi) \quad \underline{\textbf{(2e)}}$$

$$\omega_1 n^+(\omega_1,\theta,\Phi) + \omega_2 n^-(\omega_2,\theta,\Phi) + \omega_3 n^+(\omega_3,\theta,\Phi) = \omega_4 n^-(\omega_4,\theta,\Phi) \quad \underline{\textbf{(2f)}}$$

$$\omega_1 n^-(\omega_1,\theta,\Phi) + \omega_2 n^+(\omega_2,\theta,\Phi) + \omega_3 n^+(\omega_3,\theta,\Phi) = \omega_4 n^-(\omega_4,\theta,\Phi) \quad \underline{\textbf{(2g)}}$$

**Page 26, line 13**

$$n^{\pm} = \left[ \frac{2}{B \pm (B^2 - 4C)^{1/2}} \right] \quad \underline{\textbf{(4)}}$$

**Page 27, line 3 to Page 28, line 15**

*$KTiOPO_4$:* **(5)**

$$n_x^2(\lambda) = 2.1239 + \frac{0.142744\lambda^2}{\lambda^2 - 18.477} + \frac{0.87370\lambda^2}{\lambda^2 - 0.045906}$$

$$n_y^2(\lambda) = 2.0649 + \frac{0.15529\lambda^2}{\lambda^2 - 19.373} + \frac{0.95463\lambda^2}{\lambda^2 - 0.045505}$$

$$n_z^2(\lambda) = 1.6539 + \frac{0.34767\lambda^2}{\lambda^2 - 29.378} + \frac{1.6482\lambda^2}{\lambda^2 - 0.038825}$$

*$RbTiOPO_4$:* **(6)**

$$n_x^2(\lambda) = 2.15559 + \frac{0.93307\lambda^2}{\lambda^2 - 0.044075} - 0.01452\lambda^2$$

$$n_y^2(\lambda) = 2.38494 + \frac{0.73603\lambda^2}{\lambda^2 - 0.057078} - 0.01583\lambda^2$$

$$n_z^2(\lambda) = 2.27723 + \frac{1.11030\lambda^2}{\lambda^2 - 0.055009} - 0.01995\lambda^2$$

*$RbTiOAsO_4$:* **(7)**

$$n_x^2(\lambda) = 2.04207 + \frac{1.17785\lambda^2}{\lambda^2 - 0.040630} - 0.01035\lambda^2$$

$$n_y^2(\lambda) = 2.14941 + \frac{1.09267\lambda^2}{\lambda^2 - 0.046062} - 0.01067\lambda^2$$

$$n_z^2(\lambda) = 2.18962 + \frac{1.30103\lambda^2}{\lambda^2 - 0.052025} - 0.01390\lambda^2$$

*$CsTiOAsO_4$:* **(8)**

$$n_x^2(\lambda) = 2.34498 + \frac{1.04863\lambda^2}{\lambda^2 - 0.048594} - 0.01483\lambda^2$$

$$n_y^2(\lambda) = 2.74440 + \frac{0.70733\lambda^2}{\lambda^2 - 0.067772} - 0.01526\lambda^2$$

$$n_z^2(\lambda) = 2.53666 + \frac{1.10600\lambda^2}{\lambda^2 - 0.062440} - 0.01711\lambda^2$$

*KTiOAsO₄:* **(9)**

$$n_x^2(\lambda) = 2.8049 + \frac{0.35190\lambda^2}{\lambda^2 - 0.098915} - \frac{0.27186\lambda^2}{\lambda^2 + 15.798}$$

$$n_y^2(\lambda) = 2.8077 + \frac{0.37614\lambda^2}{\lambda^2 - 0.093917} - \frac{0.22531\lambda^2}{\lambda^2 + 8.6981}$$

$$n_z^2(\lambda) = 3.8510 + \frac{0.81874\lambda^2}{\lambda^2 - 86.976} - \frac{0.44017\lambda^2}{\lambda^2 + 28229}$$

*$LiNbO_3$:* **(10)**

$$n_o^2(\lambda) = 4.9048 + \frac{0.11775\lambda^2}{\lambda^2 - 0.047533} - 0.027153\lambda^2$$

$$n_e^2(\lambda) = 4.5820 + \frac{0.09921\lambda^2}{\lambda^2 - 0.044479} - 0.021940\lambda^2$$

*$LiTaO_3$:* **(11)**

$$n_e^2(\lambda) = 4.5284 + \frac{0.0095478\lambda^2}{\lambda^2 - 0.060858} + \frac{0.077690\lambda^2}{\lambda^2 - 0.033782} - 0.023670\lambda^2$$

$n_0^2(\lambda)$ Not measured (not requested)

**Page 48, line 26**

$$L_c(\alpha) = \frac{1}{\sqrt{\dfrac{\cos^2\alpha}{P_{\max}^2} + \dfrac{\sin^2\alpha}{P_{\min}^2}}} \qquad \textbf{(20)}$$